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IMPROVING SLOPE STABILITY BY ADOPTING SUITABLE BLASTING TECHNIQUES

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March, 1987

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15 pp

COAL RESEARCH LABORATORIES
DIVISION REPORT CRL 87-33 (TR)

MICROMEDIA

87-05160/

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by

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ABSTRACT

Design of open-pit slopes demands very careful evaluation of several factors influencing their stability, e.g.discontinuity surfaces, ground water, rock properties, static field stresses, dynamic stresses, etc. The ultimate coal reserves, mines safety and the overall economics of any mine operation are directly linked with it. Rock blasting in surface mining may sometimes be critical in this respect. The vibrations due to blasting may create dynamic stresses of serious levels to trigger slope failure. Blasting, can also result in the deterioration of rock properties, opening of the planes of weakness and rock fall. This may dictate designing flatter slopes with all its economic consequences. Some results have been achieved through the introduction of new blasting techniques which could improve the situation. In this paper these new design techniques have been discussed as they relate to improving slope stability.

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ACCROISSEMENT DE LA STABILITÉ DES PENTES GRÂCE À DES TECHNIQUES DE SAUTAGE APPROPRIÉES

par

B. Das* et H.G. Naidu**

RÉSUMÉ

La conception des pentes des mines à ciel ouvert nécessite une évaluation minutieuse de divers facteurs qui influencent leur stabilité, par exemple les surfaces de discontinuité, les eaux souterraines, les propriétés des roches, les contraintes statiques sur le terrain, les contraintes dynamiques, etc. Les réserves totales de charbon, la sécurité dans les mines et la rentabilité générale de toute exploitation minière sont directement liées à la conception des pentes. À cet égard, le sautage dans une mine à ciel ouvert peut parfois être critique. Les vibrations causées par le sautage peuvent créer des contraintes dynamiques suffisamment importantes pour provoquer un effondrement de la pente. Le sautage peut également entraîner la détérioration des propriétés de la roche, l'ouverture des zones faibles et l'éboulement des roches. Pour ces raisons, il peut être nécessaire de concevoir des pentes plus plates avec toutes les conséquences économiques qu'elles impliquent. L'introduction de nouvelles techniques de sautage susceptibles d'améliorer la situation a donné certains résultats. Dans le présent rapport, les auteurs discutent de ces nouvelles techniques de conception par rapport à un accroissement de la stabilité des pentes.

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CONTENTS

	Page
ABSTRACT	i
RESUME'	iii
CONTENTS	v
INTRODUCTION	1
FACTORS AFFECTING SLOPE STABILITY	1
Discontinuity Surfaces	2
Geotechnical Properties of Rocks	2
Ground Water	2
Static Field Stresses	4
Dynamic Stresses	4
EFFECT OF BLASTING ON SLOPE STABILITY	4
SLOPE STABILITY IMPROVEMENT THROUGH CONTROLLED BLASTING	5
Pre-Splitting	6
Post Splitting	8
Inclined Drilling	10
CONCLUSIONS	11
REFERENCES	11

FIGURES

Fig. 1	Planar failure along B.C. (AB - tension crack, CD - slope face)	3
Fig. 2	Bi-planer slab failure along BC and DC (AB - tension crack, DE - slope face)	3
Fig. 3	Pre-split and resultant highwalls (2)	7
Fig. 4	Comparison between front row burden with and without presplit (3)	9
Fig. 5	Inclined holes showing reflective waves at the toe (4)	10

INTRODUCTION

The major part of the Canadian coal production comes from the surface mining operations located in the three western provinces. Coal is produced from two distinct regions namely, the Prairies and the Rocky Mountains. The overburden rocks in the Prairies are soft and consist mainly of glacial till and mudstones. Blasting is generally not required there due to the soft nature of the overburden. World class draglines are utilized for handling the overburden in those coalfields. On the other hand, the rocks in the Mountains region range from soft mudstones to very hard sandstones, and therefore the overburden is blasted and removed by truck/shovel operation. In 1985, over 200 million bank cubic metres (BCM) of overburden was handled in this manner. The pit depth ranges from a few metres to over 200 metres. Design and maintenance of the open pit slopes remain one of the vital factors for safe and efficient operation of such mines. This will become more critical as mining progresses and coal extraction goes deeper. The stability of rock slopes are affected by several important factors including blasting vibrations. The original stable slope may become unstable due to the effects of blasting which deteriorates rock properties and induces dynamic stresses and thereby triggers slope failure in many cases. An analysis has been made in this paper on the effects of blasting on slope stability as well as as on the different methods of controlled blasting to minimize these effects for achieving better stability.

FACTORS AFFECTING SLOPE STABILITY

The stability of rock slopes, whether natural or man made, depends on several factors, the most important of which are the following:

- Discontinuity surfaces
- Geotechnical properties
- Ground water
- Static field stresses
- Dynamic stresses

Discontinuity Surfaces

Discontinuity surfaces are generally the weakness planes along which the rock mass may slide under critical conditions. A discontinuity surface may even be stronger than the rock substance but most commonly the reverse is true. The common examples of the discontinuity surfaces are: joints, cleats, bedding planes, fault planes, gouges, shear planes etc. There are two important geometrical configurations common in slope failure along the discontinuity surfaces namely, planar failure (sliding along a single plane) (Fig.1) and bi-planar failure (sliding along two non-parallel planes)(Fig.2).

Geotechnical Properties of Rocks

The geotechnical properties of the rocks and discontinuities are very important to slope stability. The governing properties are the cohesion and the angle of internal friction which represent the elements of triaxial strength. The other critical properties are the rheological properties and sometimes the dynamic properties when the failure is triggered by vibrations. Very often the stability of a slope is calculated using static or elastic properties but in almost all cases slope failures are due to elastic as well as time dependent behaviour of the rock mass. This is more pronounced in viscoelastic rocks as may be encountered in the rocky mountains.

Ground Water

Ground water can affect the stability of a slope in the following ways:

- Pore pressure reduces the normal stress between the opposite rock faces along a possible plane of failure, thereby reducing the shear resistance.
- Water can act as a lubricant causing reduction in the angle of friction along a failure plane.
- Water can deteriorate rock through the physical as well as chemical processes of weathering.

Therefore, a dry stable slope may become potentially unstable due to the rise of water table as well as due to percolation or flow of ground water.

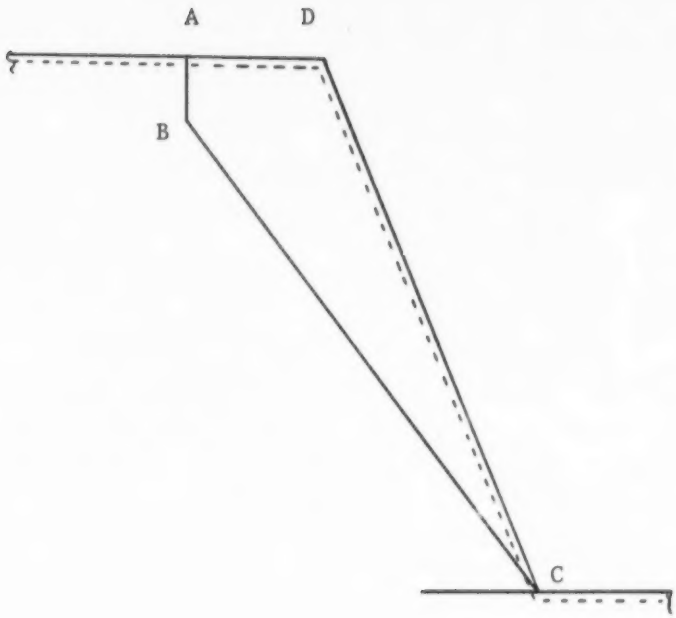


Fig. 1 Planar failure along B.C.
(AB - tension crack, CD - slope face)

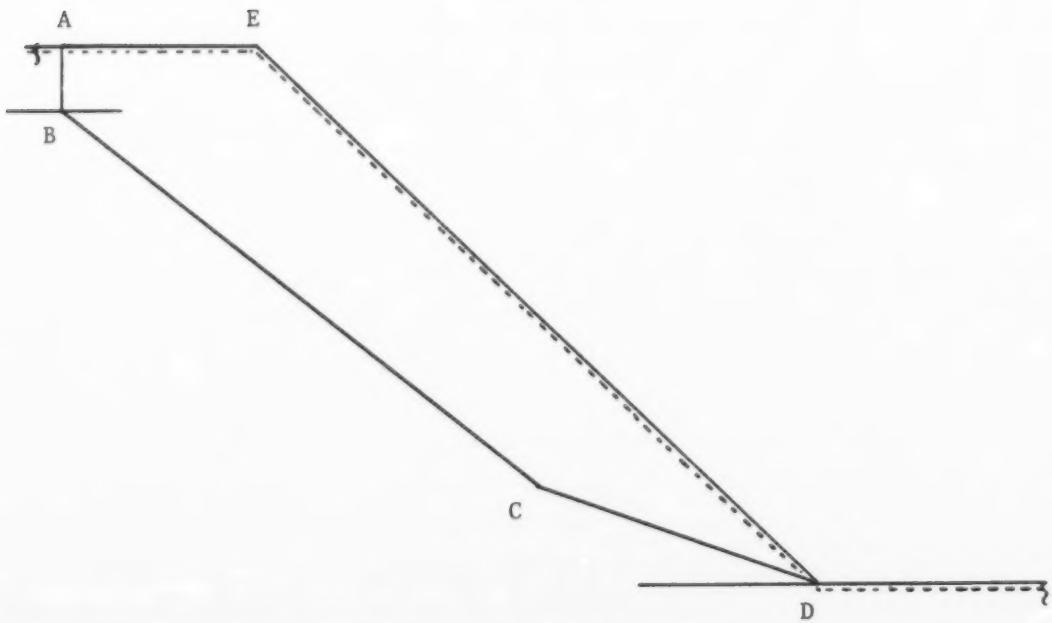


Fig. 2 Bi-planar slab failure along BC and CD
(AB - tension crack, DE - slope face)

Static Field Stresses

Two distinct types of static stresses can exist in rock strata:

- Gravitational stress (vertical)
- Tectonic stress (generally horizontal but can be in any other direction)

They can affect the stability of a rock slope by:

- Altering strength properties of rocks by creating a triaxial state of stress, the intensity of which depends on the nature of the stress vector
- By causing ground movements through deviatrix stress in an excavated face

Dynamic Stresses

Dynamic stresses may be induced in open pit rock slopes by the following:

- Rock blasting
- Earthquake
- Movement of heavy vehicles, e.g. train, trucks etc.
- Stress relief in rock mass

Of all the above causes, dynamic stresses resulting from blasting are of common concern where dynamic stresses may trigger failure of slopes that are marginally stable in static sense.

EFFECT OF BLASTING ON SLOPE STABILITY

As discussed earlier dynamic stresses may be induced in open pit slopes by several processes, rock blasting is by far the most common cause. Blasting can influence slope stability in many ways including:

- Triggering failure of a marginally stable slope due to the propagation of the vibration waves.
- Deteriorating rock properties through the formation of micro/mini fractures by repeated blasting.
- Blasting on the other hand can improve slope stability due to better drainage of ground water by improving rock permeability.

The magnitude of the dynamic stresses induced in rock slopes depends on the intensity of blasting. This intensity at a point is a function of the charge per delay, the number of delays, total charge, distance from the

blast, the type of explosive, the size, depth and the pattern of drill holes and the geotechnical properties of the rock mass. All other factors remaining constant the magnitude will generally depend on the charge per delay and the distance from the blast holes.

The magnitude of the dynamic stresses can be determined by measuring one or more of the following:

- Particle velocity
- Particle acceleration
- Particle displacement
- Displacement frequency
- Nature of the displacement waves

The degree of rock deterioration is a function of the nature of dynamic stresses and the rock's behaviour under repeated loading.

Therefore any effort to control the vibration without affecting the purpose of blasting can improve the stability of slopes which are otherwise stable under static loading conditions. These aspects are discussed in the following section.

SLOPE STABILITY IMPROVEMENT THROUGH CONTROLLED BLASTING

The easiest way of stabilizing slopes in mines is to flatten them. On the other hand, the steeper the slopes, the more favourable is the stripping ratio. Therefore, any methods which could provide increases in slope angle, without eroding safety, are worth investigating. Controlled blasting is a technique which has such a potential. Civil engineers have utilized this technique for road cuttings, canals and other surface excavations and achieved spectacular improvement in the stability of the resulting walls.

The main objectives of controlled blasting are:

- to avoid overbreak
- to eliminate back damage
- to minimize the damaging effects of the vibration by opening or causing further movement along weak planes or loose areas
- to pre-drain the ground water

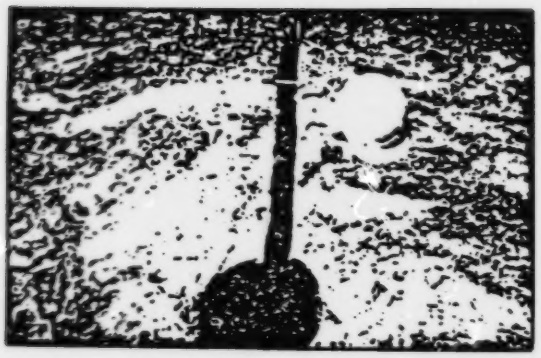
There are three forms of controlled blasting namely:

- pre-splitting
- post splitting

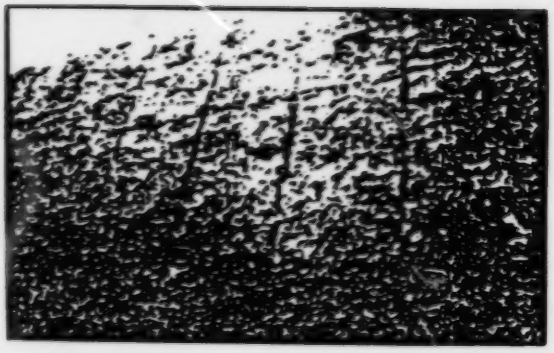
- inclined drilling

Pre-Splitting

This method fractures the rock strata along the line of the new highwall before the main blast. Pre-splitting creates a gap between the main rock body and the block of rock mass to be blasted. Due to this, the stress waves created by the main blast remain confined upto the split line and even if they cross the fracture, the intensity is much reduced resulting in less damage to the main rock body. As a result a competent highwall is formed as shown in Fig.3. Presplitting is accomplished by drilling a series of axially parallel holes in the plane of the new highwall. Each hole is charged with a decoupled explosive attached to a line of detonating cord extending over the full length of the hole. The detonating cord tail from each hole is connected to a trunk line. By initiating the trunkline, all the holes are blasted simultaneously. This means the explosive energy of all the holes is released simultaneously. The stress waves from the holes superimpose on each other so that, in the plane joining the axes of holes, the waves re-inforce to promote fracturing. This is because of the cumulative effect of the stress from the adjacent holes. At right angles to it, there is no additional energy coming from any other holes (source). The cushion effect of the air in decoupled charges reduces the apparent brittleness of the rock mass. Therefore, very little amount of the explosive energy is used up in shattering the rock mass except splitting along the plane of the pre-split holes. Simultaneous initiation which leads to the superimposition of strain effects from the adjacent holes is key to



TOP VIEW OF A HIGHWALL PRE-SPLIT



HARD HOMOGENEOUS SANDSTONE PRE-SPLIT HIGHWALL AT RIETSPRUIT

LAMINATED SHALE AND SANDSTONE PRE-SPLIT HIGHWALL AT OPTIMUM

FIG. 3 Pre-split and resultant highwalls (2).

adjacent holes is key to the splitting mechanism. By decoupling the charges the explosive energy is limited to amount which may just exceed that necessary to create the split surface, so that back damage is eliminated (Fig.4).

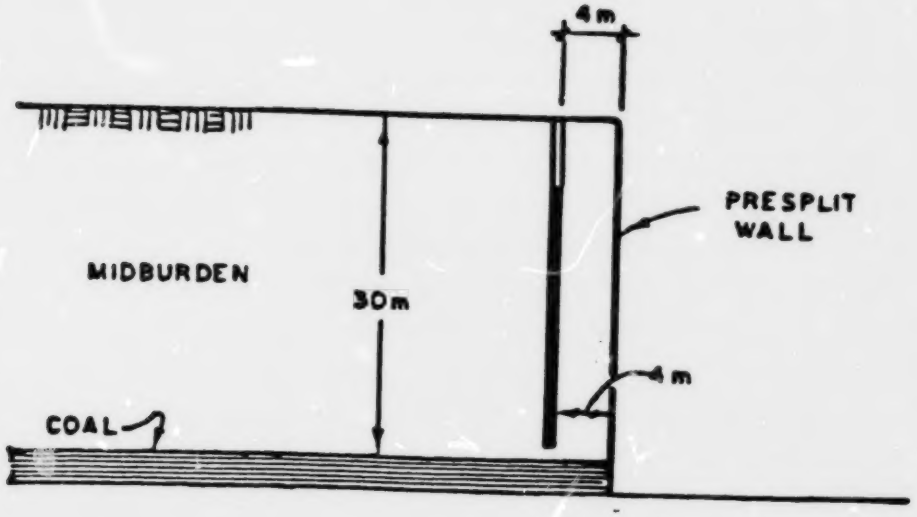
With the development of bulk explosives and their extensive usage, the methods of pre-splitting have also undergone modification. Currently this is done as follows:

- A single row of holes 250mm in diameter and 3m apart in softer overburden or 5m apart in more competent rock, is drilled to the top of the coal seam along the line of the new highwall. Each hole is then lightly loaded with 50 to 60 kg of either ANFO or slurry explosives, no stemming is used and all the holes are detonated simultaneously. This results in a competent straight highwall. In the subsequent blast it helps to control the first row of holes closest to the highwall. The problem of unblasted toe rock is completely eliminated.

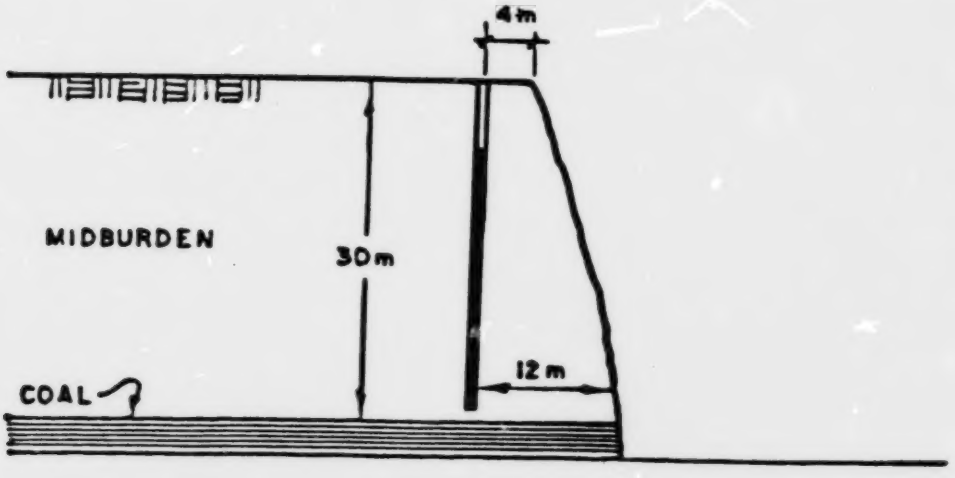
The spacing between the split holes is a very critical parameter. Normally, it should be much less than the burden. Attention must be paid to see that there is sufficient burden from the pre-split line to avoid any ground movement when these holes are blasted. The depth that can be successfully pre-split is dependent on the ability of the drill machine to maintain good hole alignment. Deviation of holes can produce unfavourable results and an uneven highwall. When a block of ground is pre-split, the infill blast of the whole block should be carried out in a single blast. This is mainly to avoid poor fragmentation.

Post Splitting

This technique is very similar to pre-splitting, the only difference being that with post splitting the split holes are fired last in the sequence as a trimming blast. All the holes are also fired simultaneously in this technique. Generally, blasting is done with a line of holes of upto 6 in. in diameter or more using explosive cartridges of diameter ranging upto about 2 in. In certain unconsolidated rock formations it is advisable to lightly charge the upper half of the holes adjacent to the split line in order to prevent these holes from breaking back beyond the split line.



(a) Front row design showing accurate control on the burden when presplit is used.



(b) Front row design showing poor control because of backbreak resulting in varying burdens when presplit is not used.

Fig. 4 Comparison between front row burden with and without presplit (3)

Inclined Drilling

Generally, vertical blast holes are drilled in surface mining. Usually this results in backbreak leaving loose broken rocks near the upper edge of the highwall as shown in Fig.4(b). Thus with vertical holes the toe burden becomes excessive and some additional explosive would be required at the lower part of the hole for effective blasting. This extra explosive produces more damaging stresses in the rock mass reducing the stability of highwalls. On the other hand, blasting with inclined holes reduces both the toe burden and the magnitude of the damaging stresses introduced into the rock face at the time of the blast. It results in more productive reflective shock waves in the critical or toe portion of the hole while the resistance of the rock against blasting is also reduced as the toe is less tight (Fig.5). With inclined drilling it is possible to increase the burden thereby reducing both drilling as well as explosive cost per unit of rock burden. The ground vibrations caused by the equivalent weight of the charges in inclined holes is much less compared to vertical holes, as in the latter case a substantial amount of the explosive energy goes into the solid block below the floor generating more vibrations. Also in inclined drilling the explosive energy in the vicinity of the collar of the holes is more usefully channelled towards the free face rather than behind the line of holes. This provides additional benefit of reduced backbreak and a more competent highwall.

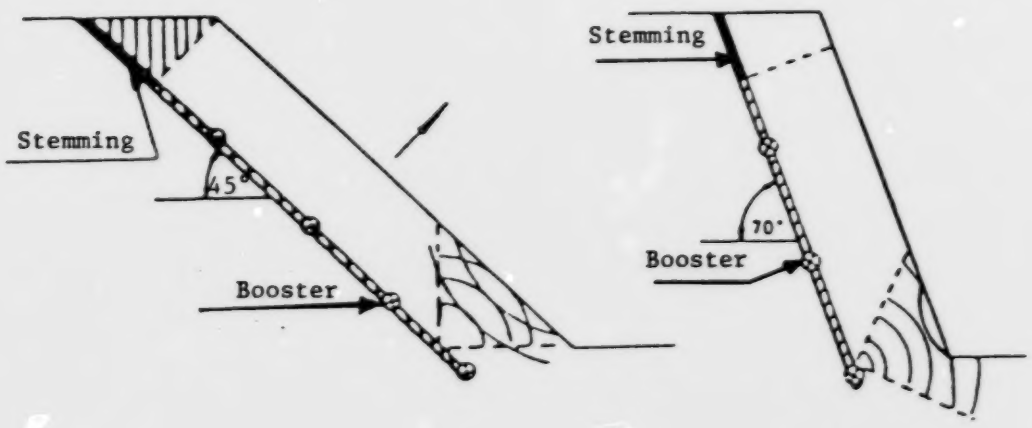


Fig. 5 Inclined holes shoving reflective waves at the toe (4).

CONCLUSIONS

Where blasting is required in surface mining, the resultant slope stability can be influenced by careful control to reduce dynamic stresses and eliminate fracturing of the host rock. Some ideas on the mechanism of the reduction of dynamic stresses have been presented here. Further study is required to make quantitative evaluation of stability improvement.

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